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A Comparative Analysis of Results from Three Recent Non-Separated Concurrent-Flow High Occupancy Freeway Lane Projects: Boston, Santa Monica and Miami

Final Report
June 1978

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16. Abstract

Results from three recent non-separated concurrent-flow high occupancy freeway lane projects; Boston's Southeast Expressway, the Santa Monica Freeway in Los Angeles, and Miami's I-95 are compared. The project sites and projects are described and contrasted. The following issue areas are explored: supply - changes in travel times on the freeways, changes in transit level of service; demand - modal shift to carpooling and transit induced by the reserved lane; project costs - capital and operating, including express bus costs; safety and enforcement - changes in accidents and incidents, violation rates, enforcement; and institutions and attitudes - the public's attitude towards the reserved lane concept, the effect of advertising and media reports, the role of politics.

The three projects met with differing degrees of success and failure, and those in Boston and Los Angeles have been terminated. Carpooling increased by about 70 percent at the three sites and travel times for those using the reserved lanes decreased. However, the projects revealed several weaknesses in the concept: the large number of violators and the difficulty of enforcement; the potential for accidents; the inability of the reserved lanes by themselves to attract large numbers of new bus riders and carpoolers; and the political problems associated with removing an already existing lane from general use. The evidence indicated that there should be a median strip between the two directions of flow, a permanent barrier between the reserved and regular lanes, and a limited number of reserved lane access points.

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PREFACE

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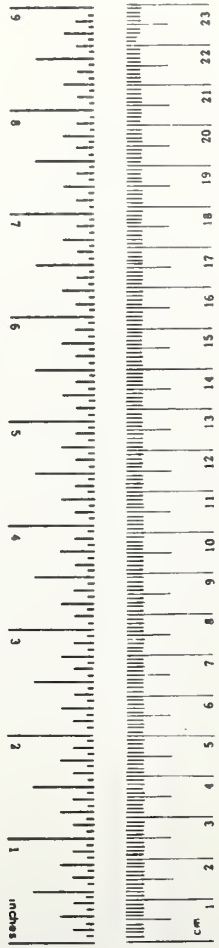
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.036	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
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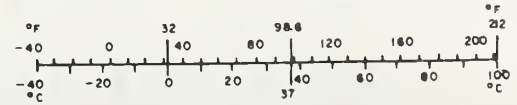

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1. BACKGROUND

In order to move more people in fewer vehicles, and with a limited capital investment, a set of priority techniques for high occupancy vehicles (HOV) has been developed and implemented over the past several years. These traffic management options include concurrent-flow, contra-flow, and reversible lanes on arterials and freeways, exclusive lanes that bypass congested areas such as freeway ramps and toll plazas, exclusive access ramps to freeways, bus pre-emption of traffic signals, congestion pricing, transit malls, and auto restricted zones.

This analysis focuses on recent experience with non-separated concurrent-flow high occupancy lanes on freeways. For the remainder of this paper, the term "reserved" will be used to denote these lanes. Reserved lanes exist or have existed on Route 101 and Route 280 in San Francisco, on the Santa Monica Freeway in Los Angeles, on the Banfield Freeway in Portland, on the Southeast Expressway in Boston, on I-95 in Miami, and on the Moanalua Freeway in Honolulu.

The potential benefits of a reserved lane are enormous. For example, while one freeway lane with an average occupancy of 1.3 persons per car can carry only 2600 persons per hour, when the occupancy is increased to 4 persons the hourly person throughput rises to 8000. Unfortunately, these idealized outcomes have yet to be realized by non-separated concurrent-flow reserved lane projects.

Through a comparative analysis of results of the three most recent concurrent-flow projects, Boston's Southeast Expressway, I-95 in Miami, and the Santa Monica Freeway, this paper attempts to develop a better understanding of the issues surrounding the reserved lane concept. Boston, Miami, and Santa Monica were chosen for comparative analysis for several reasons: all three represent recent experiments with the reserved lane concept; the three projects and project sites exhibit substantial differences; and evaluation efforts were conducted at each site. The following questions are addressed:

Supply: How does a reserved lane affect travel times and congestion on the freeways and alternate routes? How are transit travel times and reliability affected?

Demand: Does implementation of a reserved lane result in a modal shift to carpooling and transit?

Safety and Enforcement: Does the reserved lane increase the number and severity of accidents on the freeway? What is the violation rate and how can it best be reduced? What is the need for and cost of enforcement?

Institutions and Attitudes: What is the public's attitude towards the reserved lane concept? What role does politics play in reserved lane projects? What are the effects of advertising and media reports?

Costs: What are the costs involved in setting up and operating a reserved lane project? What are the costs related to express bus operations?

Design: What design and operating environment are most appropriate to the reserved lane concept?

The following section provides the background material necessary to address these questions. The remainder of the paper is divided into the following issue areas: supply, demand, safety and enforcement, institutions and attitudes, costs, and design.

2. SITE AND PROJECT DESCRIPTIONS

2.1 Site Characteristics

Table 2.1. provides relevant demographic and socio-economic data for each of the 3 project cities under consideration. The Los Angeles urbanized area is considerably larger in size than Miami's and Boston's and contains a proportionately higher population. The Boston urbanized area has the lowest population and employment densities of the three sites due to the large amounts of wooded areas in the region. In Los Angeles and Miami residential and commerical activities are distributed more uniformly over the region. This is indicated by the figures for the central city and the central business district (CBD). The population and employment densities for Boston's central city are considerably higher than those for Los Angeles and Miami. Of the 3 CBD's, Boston's has the highest employment.

Table 2.2. contains the relevant characteristics of the specific corridor study areas served by the reserved lane projects. The project corridors are shown in uniform scale in Figure 2.1. Boston's South Shore Corridor extends along the Massachusetts Bay shore from Boston to Duxbury, 25 miles south of the Boston CBD. The market area began 9 miles south of the CBD at the entrance to the reserved lane, just north of the intersection of Routes 3 and 128. The majority of the trips eligible for the reserved lanes originated in an area between this point and 10 miles to the south of this point, 10 miles east to the Atlantic Ocean, and 10 miles west to I-95.

The Santa Monica study area, called the Westside study area, is a fully-developed urban region in West Central Los Angeles County. The transit market area is bounded by La Cienega Boulevard on the east, the Pacific Ocean on the

TABLE 2.1. DEMOGRAPHIC AND SOCIO-ECONOMIC DATA FOR PROJECT CITIES

		BOSTON	LOS ANGELES	MIAMI
URBANIZED AREA:	TOTAL POPULATION	2,653,000	8,351,266	1,219,661
	LAND AREA	644	1,572	259
	POPULATION DENSITY	3,992	5,313	4,715
	EMPLOYMENT DENSITY	1,754	2,132	1,954
CENTRAL CITY:	TOTAL POPULATION	641,000	3,169,000	335,000
	LAND AREA	46	512	34
	POPULATION DENSITY	13,936	5,184	9,763
	EMPLOYMENT DENSITY	9,609	2,698	6,265
CBD:	TOTAL POPULATION	3,700	22,150	3,274
	LAND AREA	1.0	2.76	.395
	POPULATION DENSITY	3,700	8,022	8,282
	EMPLOYMENT DENSITY	91,000	51,071	65,000
WORK TRIP MODE SPLIT FOR THOSE LIVING IN URBANIZED AREA (%)				
	AUTO DRIVER OR PASSENGER	67	87	83
	PUBLIC TRANSPORTATION	19	5	9
	WALK	11	6	6
	TAXI	3	2	2

TABLE 2.2. STUDY AREA CHARACTERISTICS

	BOSTON	LOS ANGELES	MIAMI
PROJECT MARKET AREA (TRIP ORIGIN)			
POPULATION	249,000	616,000	660,000
LAND AREA (SQUARE MILE)	225	100	261
POPULATION DENSITY (PERSONS/SQ. MILE)	1,106	6,200	2,529
LAND USE	PRIMARILY RESIDENTIAL	PRIMARILY RESIDENTIAL	PRIMARILY RESIDENTIAL
HOUSEHOLD MEDIAN INCOME (DOLLARS)	12,500	12,400	9,600
PERCENT OF WORKERS IN MARKET AREA WORKING IN PROJECT EMPLOYMENT AREAS	20	3.3	10
WORK TRIP MODE SPLIT FROM MARKET AREA TO PROJECT EMPLOYMENT AREA			
AUTO DRIVER	[40]	71	[98]
AUTO PASSENGER		6	
TRANSIT	60	16	2
OTHER	-	7	-
PROJECT EMPLOYMENT AREA (TRIP DESTINATION)			
EMPLOYMENT AREA (SQUARE MILES)	3.37	2.76	23
EMPLOYMENT	200,000	141,000	141,000
EMPLOYMENT DENSITY (WORKERS/SQ. MILE)	59,347	51,071	6,130
			-

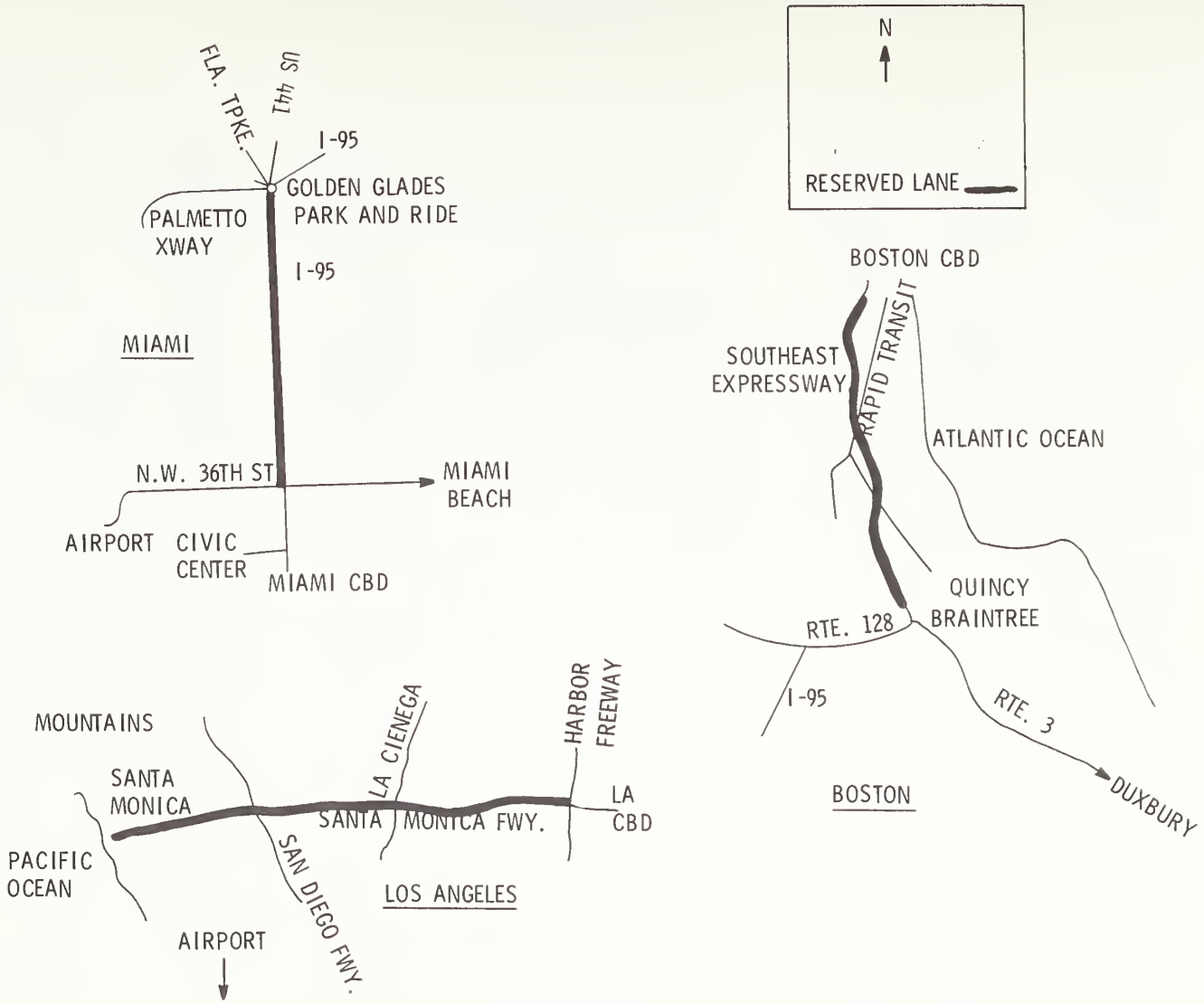


FIGURE 2.1. SCALE DRAWINGS OF THE THREE PROJECTS

west, the Los Angeles International Airport on the south and the Santa Monica Mountains on the north. Since carpools are free to enter the reserved lanes at any point between Santa Monica and the CBD, their market area extends further east. It is 14 miles to the Los Angeles CBD from the Pacific Ocean at Santa Monica.

The Miami I-95 project transit market area extends to the east, north, and west of the Golden Glades Interchange through northern Dade County and southern Broward County. The carpool market area extends further into the CBD. The I-95 corridor connects these populous residential areas to the north of Miami to four major employment centers in central Miami: downtown Miami, the Civic Center, the Airport, and N.W. 36th Street. It is approximately 11 miles from the Golden Glades Interchange to the Miami CBD.

The Los Angeles capture area exhibits the highest population density. The low density in Boston is, as stated earlier, due to the large amounts of forest and park land in the corridor. The primary land use in all three capture areas is residential.

The Boston capture area is highly oriented toward the regional core. For the communities within 10 miles south of the beginning of the lane, 20 percent of all work trips are made to the center of Boston. In Los Angeles only 3.3 percent of all work trips are made to the CBD, the only destination of the express buses. A large proportion of Westside inhabitants work in the study area while the remaining ones have jobs distributed throughout the region. In Miami, 10 percent of the work trips originating in the project market area are destined for one of the 4 center city destinations served by the express buses.

The work trip mode splits for market area workers employed in the destinations served by the project vary significantly among the sites. The mode split is 60 percent in Boston, 16 percent in Los Angeles, and only 2 percent in Miami.

2.2 Transit

Boston provides far more public transportation than do Miami and Los Angeles. Seat miles per capita at rush hours for the three cities are as follows:

	Boston	Miami	LA
Bus transit	.30	.38	.28
Rapid rail	.20	-	-
Commuter rail	.07	-	-

The transit travel options available to the Boston commuter are much greater than to those living in Miami or Los Angeles. Boston's South Shore Corridor is served by the

Southeast Expressway, numerous arterials, a rapid transit line, feeder and express bus routes connecting with the rapid transit, express bus routes operating into the Boston CBD via the Southeast Expressway, and commuter rail and commuter boat. Peak period rapid transit headways are 5 minutes while buses operate on 5 to 30 minute headways.

In addition to the Freeway, the Santa Monica Freeway corridor contains numerous arterials, and there is local bus service as well as express bus service both on and off the Freeway. Before the Santa Monica diamond lane project, only four feeder/express routes operated on the Freeway.

Prior to the start of the I-95/N.W. 7th Avenue Bus/Carpool Project in Miami there were only three express bus routes providing service between residential communities in northern Dade and southern Broward Counties and two employment centers, downtown Miami and N.W. 36th Street. These buses made 18 daily trips, 9 during each peak period. All other bus service in the study area was on local arterials. Rapid transit, commuter rail, and commuter boat are not available in Miami or Los Angeles.

2.3 Description of Reserved Lane Projects

The three reserved lane projects, even though each involved the concurrent-flow high occupancy vehicle lane concept, differed significantly from each other as to physical design of the freeways, hours of operation, entrance ramp treatment, transit characteristics, and other project related activities. Table 2.3. summarizes the key descriptors of the three preferential lane projects.

Boston's Southeast Expressway carries 121,000 vehicles per day, the Santa Monica Freeway carries 240,000 vehicles per day, and Miami's I-95 carries 170,000 vehicles per day. In Miami a lane for high occupancy vehicles was added to I-95 in both directions, completely eliminating the median area. In both Boston and Los Angeles existing lanes were taken away from normal use and dedicated to high occupancy vehicles. In Boston the left lane in the northbound (inbound) direction only was reserved for buses and carpools of three or more occupants from 6:30 a.m. to 9:30 a.m. during weekdays. In Los Angeles the lanes were reserved for buses and carpools of three or more occupants in both directions from 6:30 a.m. to 9:30 a.m. and 3:00 p.m. to 7:00 p.m. In Miami the southbound (inbound) lane was restricted to buses and carpools of 3 or more occupants from 6:00 a.m. to 10:00 a.m. and the northbound (outbound) lane from 3:00 p.m. to 7:00 p.m. After a year of operations the times were changed to 7:00 a.m. to 9:00 a.m. and 4:00 p.m. to 6:00 p.m. and the restrictions changed to carpools with 2 or more occupants.

Access into and out of the lanes in Los Angeles and Miami was unrestricted. In Boston, plastic inserts spaced

TABLE 2.3. COMPARISON OF THE THREE PREFERENTIAL LANE PROJECTS

PROJECT	FACILITY	LENGTH (miles)	OPERATING DATES	LANE RESTRICTIONS	LANE ORIGIN	HOURS OF OPERATION	SPECIAL FACILITIES
Boston: Southeast Expressway	Freeway, 3 or 4 lanes each direction, including use of shoulder in peak direction during peak period	8	5/04/77-11/02/77	Buses and carpools (3 or more occupants)	1 existing lane reserved (inbound)	6:30-9:30 a.m. inbound only	Plastic inserts space 20-40 feet, freeway "metering" for 3 months
Miami: I-95	Freeway, 4 or 5 lanes each direction	7.5	3/15/76-present	Buses and carpools (3 or more occupants, changed to 2 or more)	2 lanes built in median area	6-10 a.m. (changed to 7-9 a.m.) inbound; 3-7 p.m. (changed to 4-6 p.m.) outbound	Flyover connecting major park and ride lot to I-95 after one year
Los Angeles: Santa Monica Freeway	Freeway, 4 or 5 lanes each direction	12.9	3/15/76-8/09/76	Buses and carpools (3 or more occupants)	2 existing lanes reserved	6-10 a.m. (changed to 6:30-9:30 a.m.) 3-7 p.m. inbound and outbound	Ramp metering, some with preferential bypass
Portland Oregon: Banfield Freeway	Freeway, 3 or 4 lanes each direction	3.3	12/15/75 present	Buses and carpools (3 or more occupants	resurfaced, removed shoulder, narrowed lanes	24 hours/day changed to 6:30-9:30 a.m. inbound and 3:30-6:30 p.m. outbound	

TABLE 2.3. COMPARISON OF THE THREE PREFERENTIAL LANE PROJECTS (Cont.)

PROJECT	ACCESS/EGRESS	ENFORCEMENT	TRANSIT	EXPRESS BUS AVERAGE FARE
Boston: Southeast Expressway	Only at beginning and end	Voluntary for first 5 months, enforced last 2-1/2 weeks; increase in police	Minor changes to existing express and feeder bus, rapid rail, commuter rail, and commuter boat; new park and ride route	$1.25
Miami: I-95	Unlimited	Little enforcement; no increase in police	Park and ride and feeder/express bus service increased from 18 to 52 trips per day; new large park and ride lot	.60
Los Angeles: Santa Monica Freeway	Unlimited	Fifty percent increase in police, reduced to normal by 12th week	Four existing feeder/express bus routes increased to 9; 3 new park and ride routes and lots	.61

at 20 or 40 foot intervals separated the lane from the rest of the roadway and entry to or exit from the lane was allowed only at the beginning and the end. Weaving was prohibited but only sporadically enforced by the police.

Only Los Angeles employed ramp metering. Thirty on-ramps were equipped with meters (these existed before the project), and their timing was adjusted and pre-set to maintain free flow on the Freeway. Twelve of these ramps offered preferential access to buses and vehicles with two or more occupants. During the first three months of operation, the left lane on Boston's Southeast Expressway was blocked just before the beginning of the reserved lane and all vehicles had to merge into the right lanes (see Figure 2.2.). This made it necessary for carpools and buses (and violators) to switch back into the reserved lane. The effect was similar to metering the Expressway. In Miami, a flyover providing a direct connection between the major park and ride lot and the reserved lane was opened 12 months after the start of the project.

While all three sites stressed the need to use the existing freeways in a more efficient manner and to reduce energy consumption and air pollution by encouraging the use of high occupancy vehicles, the motivating force behind the reserved lane project in Boston was the need to reconstruct a portion of the roadway that would create a temporary decrease in capacity of up to 25 percent. The potential for serious congestion and the need for preferential treatment for high occupancy vehicles was clearly explained to the public.

The lane restrictions were heavily enforced in Los Angeles and only lightly enforced in Miami. The restrictions were voluntary in Boston during the first five months of operations, after which time enforcement was instituted by sending traffic citations through the mail.

In Boston few changes were made to the existing very extensive public transportation systems. One park and ride route was added and back-up sections on existing bus and rapid rail routes were provided. Additional fringe parking spaces were made available.

In Los Angeles, up to twelve bus routes used the diamond lane. Five of the routes were new feeder express routes from the Westside area to the Los Angeles CBD. Three new routes provided service to the new park-and-ride lots. In all, the number of morning express bus runs was increased from 18 to 74. Headways on all the routes were 10 to 15 minutes.

In Miami the express bus service was expanded in 1974. Not only was the express bus service increased to 55 trips per day, but also the size of the market area served was

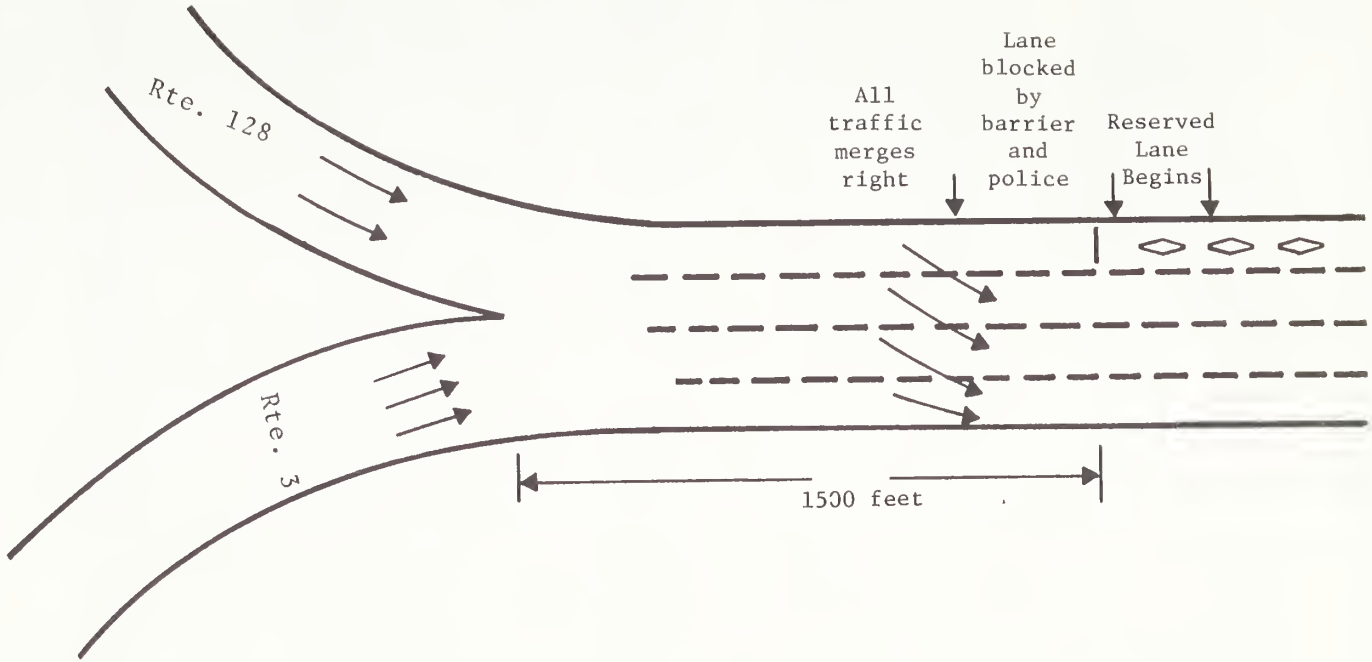


FIGURE 2.2. BLOCKED LANE ENTRY AND MERGE RIGHT

increased: at the northern end of the corridor, express buses provided increased residential coverage to the northwest and northeast of the Golden Glades interchange; at the southern portion of the corridor, the buses served two employment centers (Civic Center and Airport) where service had, up to this point, been very limited.

A parking lot with space for 1320 vehicles was constructed at the northern end of the reserved lanes at Golden Glades, the confluence of 5 major highways. The lot was fenced, well lit, and patrolled. Some bus runs originated at this parking lot, while others performed local collection service before converging at the lot to pick up park-and-ride, kiss-and-ride, and transfer passengers. The buses then traveled south along I-95 destined for one of four major employment centers.

The Golden Glades Parking Lot, by acting as a transfer point for the four feeder routes as well as a park-and-ride and kiss-and-ride facility, enabled travel between any point in the residential market area and any employment destination, whereas the former express bus service only operated between selected origins and destinations, with no transfer capability. Furthermore, the three new feeder routes provided far more efficient and direct service in the residential area than the three express bus routes that they replaced.

In Boston and Los Angeles, computer carpool matching, a marketing campaign, and a telephone center were provided to assist and encourage travelers to use the reserved lanes. In Miami, only a marketing effort was undertaken.

In Miami, the lanes are still in operation although the definition of a carpool has been changed from three to two occupants. In Boston the police began enforcing the lane restriction 5 months after the project began. After two and one-half weeks of significant political pressure and unfavorable articles in one of the daily newspapers, the Commissioner of the Massachusetts Department of Public Works suspended the project. In Los Angeles, a Federal judge ruled that an environmental impact report should have been filed under both federal and state environmental laws. This ended the Santa Monica project after 21 weeks of operation.

3. TRAVEL TIMES AND TRANSIT LEVEL OF SERVICE

This section discusses changes in travel times on the freeways and alternate routes and changes in transit level of service.

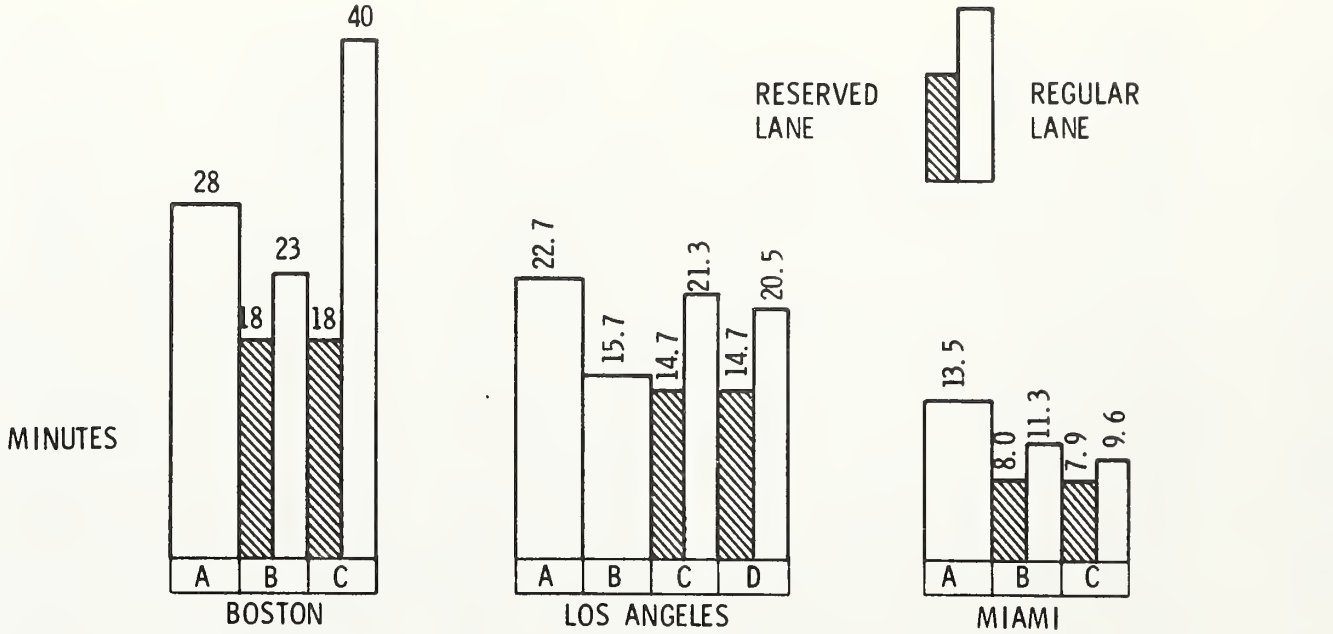
3.1 Freeway Travel Times

Figure 3.1. summarizes the changes in freeway travel times. At all three sites the projects led to a decrease in travel times for users of the reserved lanes. In Miami, where vehicle and person throughput increased, travel times decreased for everyone due to the 25 to 35 percent increase in freeway capacity.

In Boston, travel times also decreased for all users of the Expressway during the non-enforcement period. This was a result of the shift of people out of single occupant autos into carpools and buses on the Expressway and to other modes and routes. It was also due to the "metering" of the Expressway at the beginning of the lane. The time delay caused by the merge to the right was more than compensated for by the free-flow conditions on the Expressway north of the merge. A carpool traveling an 11.4 mile segment that included the merge delay and the 8 miles of reserved lane at 7:30 a.m. had its time reduced from 28 to 18 minutes, a decrease in travel time of 36 percent. For a non-carpool, the decrease was less substantial, 5 minutes or 18 percent. Persons entering the Expressway closer to the Boston CBD also experienced a decrease in travel time. While persons entering after the Route 128/Route 3 merge were not legally eligible for the reserved lane, they now entered a free-flowing Expressway and did not experience the delay caused by the metering. During the two and a-half weeks that the lane was enforced, travel times for non-high occupancy vehicles averaged 7.5 minutes longer than before the project. The metering was no longer in effect and many of the violators had switched to the unreserved lanes. The limited data collected during this period indicated that the system had not yet reached equilibrium and that the travel times were gradually decreasing as more people found alternative modes and routes of travel.

In Los Angeles, while the total number of vehicles using the facility decreased, travel times in the regular lanes increased. The ramp meters that had been installed over the previous year had made the average trip time both shorter and less variable; the reserved lane project made travel in the non-priority lanes longer and less predictable.

Travel in the reserved lanes was free flowing with an average speed of 54.3 miles per hour. However, there were delays in crossing three lanes of traffic to access and leave the diamond lanes. As the project progressed, travel times in the regular lanes tended to decrease as the ramp meters were more finely tuned. For example, in the morning eastbound direction travel time for the same trip was 22.7 minutes a year before the project, fell to 15.7 minutes when ramp meters were installed (prior to the diamond lanes), rose to 21.3 minutes during the first seven weeks of



11.4 MILES, 7:30 A.M.

A. BEFORE
B. DURING - PRE-ENFORCEMENT
C. DURING - ENFORCEMENT

12.9 MILES, 6:30-9:30 A.M.
INBOUND

A. BEFORE METER AND LANE
B. RAMP MEETING ONLY
C. DURING - 1ST 7 WEEKS RESERVED LANE
D. DURING - LAST 7 WEEKS RESERVED LANE

6.68 MILES 4-6 P.M.
OUTBOUND

A. BEFORE - 1974
B. DURING - 3 PERSON PHASE
C. DURING - 2 PERSON PHASE

FIGURE 3.1. FREEWAY TRAVEL TIMES

reserved lane operation (a 29 percent increase over the time when there was only ramp metering) and was 20.5 minutes during the project's final seven weeks, a decrease of 4 percent from initial project travel times. Note that this time was less than when there had been no ramp metering.

Wait times on entry ramps onto the Southeast Expressway decreased during the non-enforcement period. Data was not collected during the enforcement phase. In Los Angeles meters were used on all entry ramps to control the number of cars entering the Freeway according to volumes on the facility. The metering rates were adjusted previous to the opening of the diamond lanes. In most cases the queue length and wait times increased. The largest peak hour increase was 5 minutes. Total Freeway trip times, including ramp and Freeway travel times, increased by about 6 minutes for non-carpoolers. No ramp data was collected in Miami.

3.2 Transit Level of Service

Bus passengers on the three freeways experienced a decrease in travel time similar to that for carpoolers (see Figure 3.2.). In Boston 55 buses traveled the facility between 7:00 a.m. and 8:00 a.m. For this time period the average reserved lane travel time was 18 minutes, a 36 percent decrease from the 28 minute travel time recorded during the March pre-implementation period. There were no perceptible changes in travel times for other transit modes.

Miami's express buses traveled on the regular lanes on I-95 from April to August 1974 and then used the parallel N.W. 7th Avenue reversible lanes until March 1976 when they were transferred to the just completed I-95 reserved lanes. The afternoon buses, most of which travelled during the peak hour, experienced a decrease in travel time of 40 percent (12.8 minutes to 7.8 minutes) during the 3 person carpool requirement phase and a decrease of 27 percent (to 9.4 minutes) during the 2 person carpool requirement phase.

In Los Angeles, a sample of 15 possible bus trips from the Westside study area to the CBD took an average of 57 minutes before the project and 33 minutes with the diamond lanes, a decrease of 42 percent. Some of this reduction was due to the new freeway express service that made the taking of local buses unnecessary.

In Los Angeles there was significant evidence that bus arrival time reliability improved as a result of the diamond lanes. In Miami average time late decreased during the 3 person phase and increased during the 2 person phase. Variability of arrival time was greatest during the 3 person phase. It could be that during this period drivers had the most discretion in setting their speed since the reserved lane was free flowing.

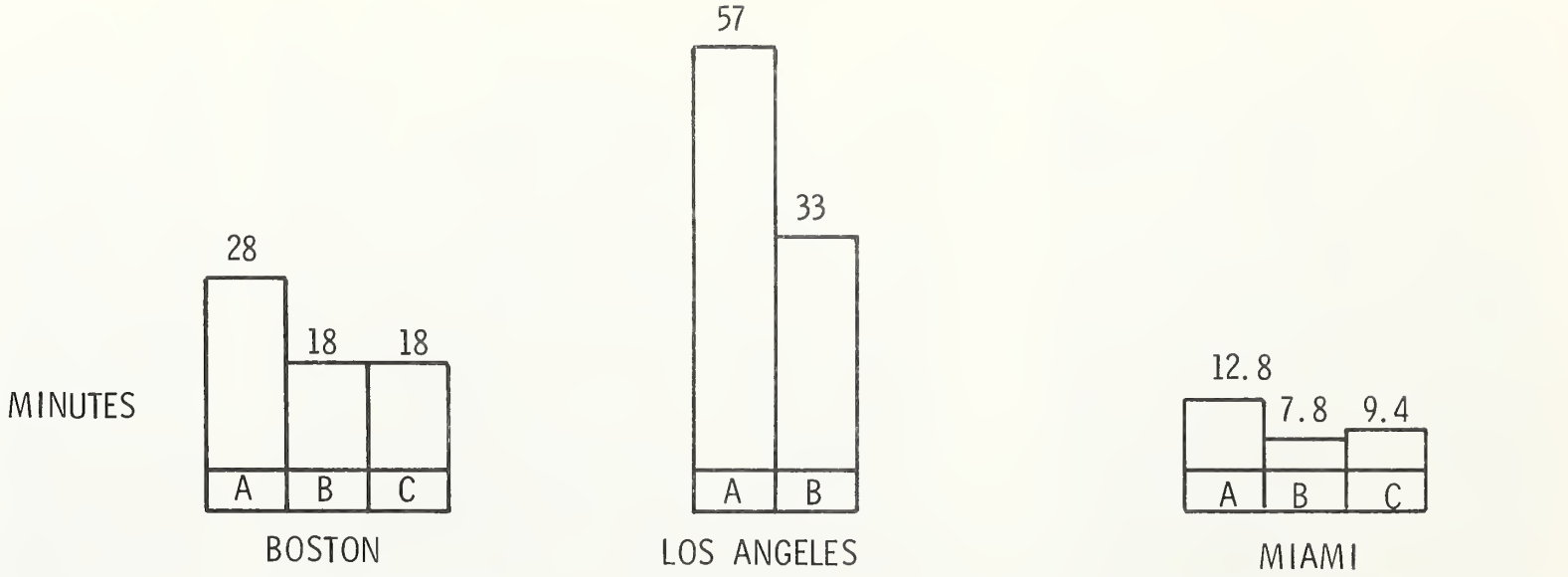


FIGURE 3.2. EXPRESS BUS TRAVEL TIMES

At all three sites there were other improvements in transit level of service such as decreased headways and increased coverage through new routes. Section 4 discusses how these changes led to changes in demand. The largest increase in coverage and decrease in headways was in Los Angeles where the number of express bus trips was quadrupled, more than doubling the number of Westside CBD workers living within walking distance of express bus service. Before the project there were 18 express bus trips every morning from the Westside area to the CBD. On the first day of the project there were 74 trips. Not only was coverage increased but headways were significantly reduced.

In Miami, the number of morning express bus trips was increased from 9 to 47 and then cut to the 26 most profitable runs. In Boston, where public transit was already of high quality, there was little change made to the existing service. Contingency plans were formulated in case an increase in transit supply was needed. One private carrier ran five buses at 20-minute headways from two commuter parking lots near Route 128 on the Southeast Expressway to Government Center in the Boston CBD. However, since ridership was very low, this service was discontinued after two months of operation.

4. TRANSPORTATION SYSTEM USE PATTERNS

In this section changes in the use of the transportation systems are compared for the three projects. Topics covered include freeway use patterns, alternate route use patterns, and transit use patterns. The impacts due to seasonal considerations are not fully understood at the three sites, although one can assume that traffic generally declines during the summer months.

4.1 Freeway Use Patterns

The number of vehicles travelling the freeways in both Boston and Los Angeles decreased when the reserved lanes were opened. In Boston vehicle throughput during the three operating hours declined by 9 percent in May, from 16,200 to 14,800 and by another one percent in June, down to 14,600. This additional decrease in vehicle throughput was probably a result of the roadway construction and seasonal factors. During the enforcement phase 13,900 cars passed the screenline, a decrease of 21 percent.

During the first seven weeks of lane operation in Los Angeles, the decline in Freeway volumes during the 7 hours of operation was 32 percent, from 113,000 to 77,000. Vehicle volumes in Los Angeles rose to 102,000 during the last seven weeks of operation, 9 percent less than before project implementation.

In Miami, the number of vehicles travelling I-95 during the morning peak period in the southbound direction increased from 15,200 before the reserved lanes opened to 15,900 during the three person phase, an increase of 5 percent and to 18,200 during the two person period, an increase of 20 percent. Figure 4.1. summarizes the changes in freeway vehicle throughput at the three sites.

As with vehicle throughput, person throughput declined in Boston and Los Angeles, but by a much smaller percentage, reflecting a switch to high occupancy vehicles. In Boston, person throughput during the 3 hours of lane operation fell from 23,600 in March to 22,400 in May, a 5 percent decrease. In June person throughput averaged 22,300, a decrease of an additonal one percent. During the enforcement phase it was 21,600, 8 percent less than in March.

In Los Angeles, the decline during the first seven weeks of operation was 27 percent, from 139,000 to 102,000. Person throughput rose to 136,000 by the last seven-week period of the project, only 2 percent less than the pre-project level.

In Miami, the number of persons in the southbound direction during the morning peak increased from 18,600 before the reserved lanes opened to 21,200 during the 3 person phase, an increase of 14 percent and to 23,800 during the 2 person phase, an increase of 28 percent. Note that these increases included riders on all the express buses that had been rerouted from N.W. 7th Avenue to I-95. Figure 4.2. summarizes the changes in freeway person throughput for the three projects.

The number of carpools increased at all three sites (see Figure 4.3.). In Boston, the increase was from 680 in March to 900 in May and June, an increase of 32 percent. Just before the termination of the project 1170 carpools were recorded at the screenline, an increase of 72 percent from the before period. Since the enforcement phase lasted only two and one-half weeks, carpool formation had probably not yet reached equilibrium. The special carpool matching program resulted in 400 persons filling out carpool request forms. It is not known how many of these persons formed carpools.

In Los Angeles, the total number of carpools during the 7 hours of operation increased from 3479 before to 4345 during the first seven weeks of the project, an increase of 25 percent, and to 5749 during the last seven weeks, an increase of 65 percent. After the project ended the number of carpools fell to within 5 percent of pre-project levels. Commuter computer estimated that it was responsible for the formation of 193 carpools.

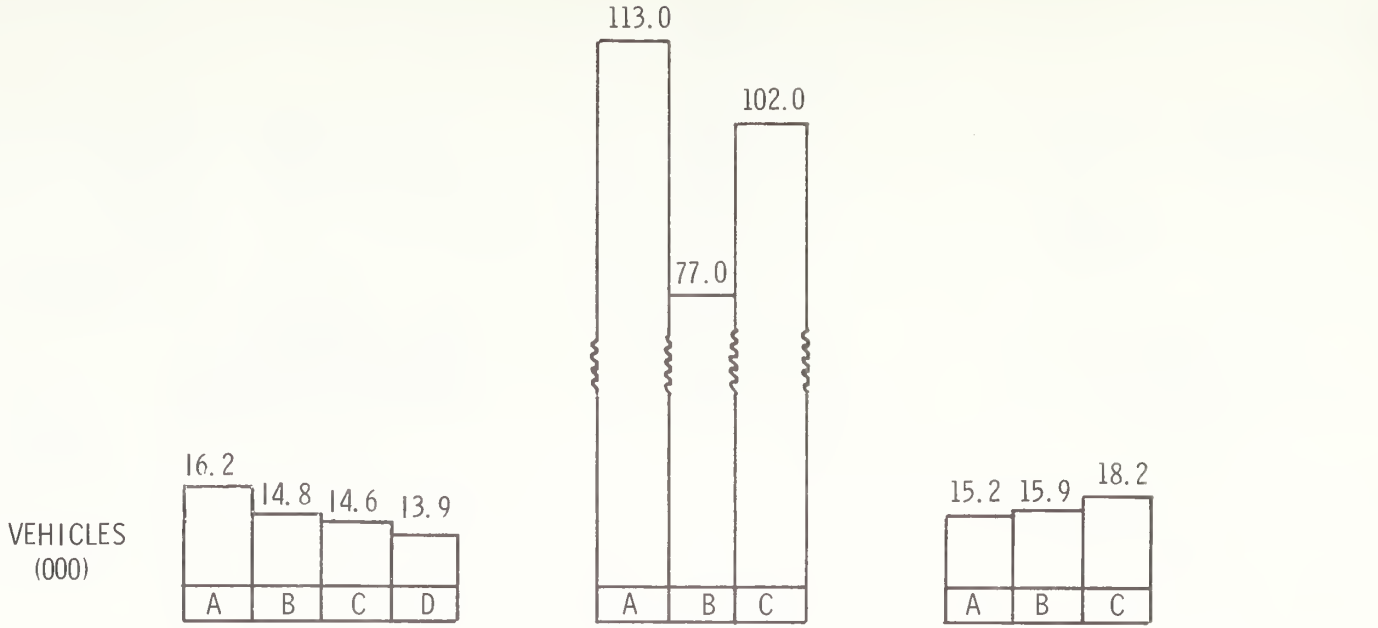


FIGURE 4.1. FREEWAY VEHICLE THROUGHPUT

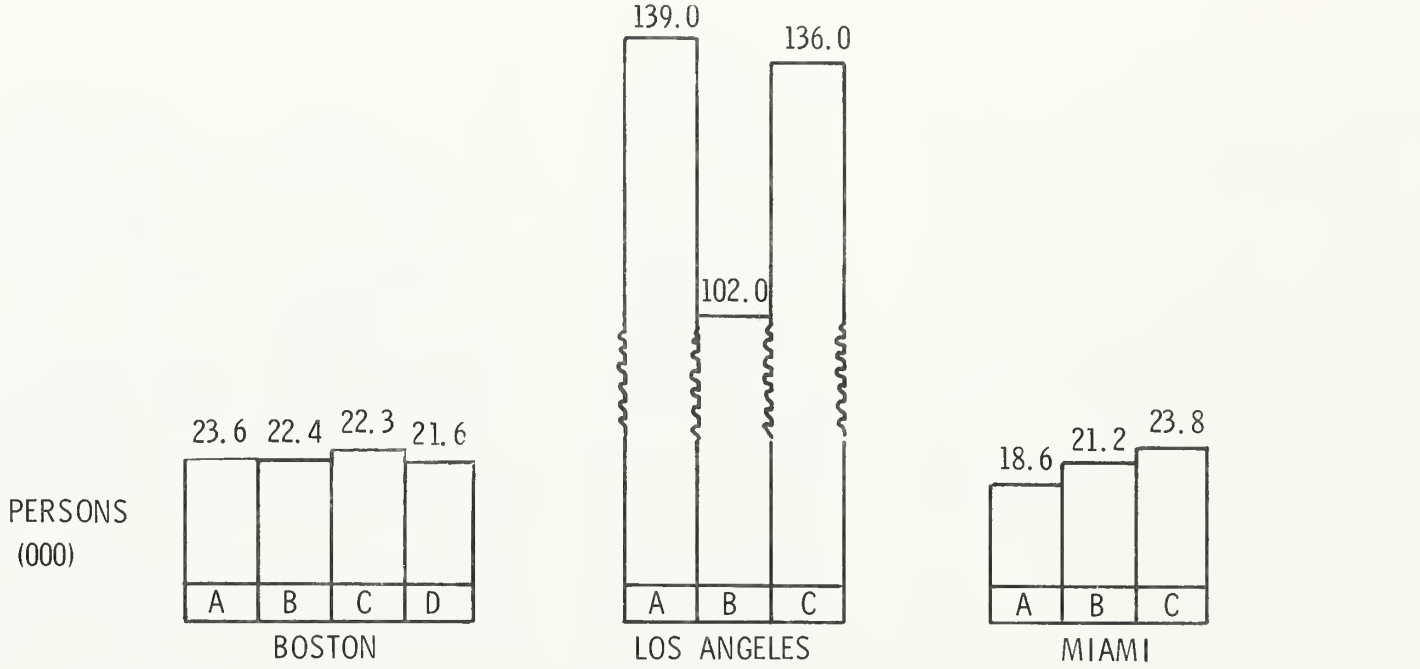
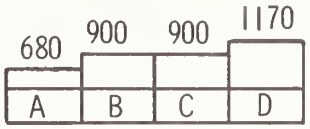


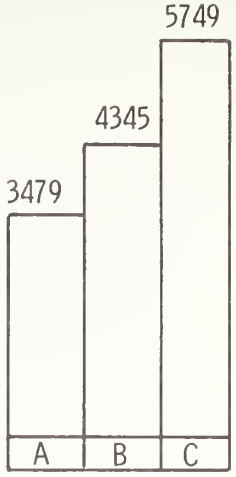
FIGURE 4.2. FREEWAY PERSON THROUGHPUT

CARPOOLS



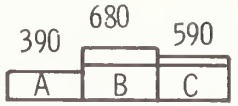
BOSTON

6:30-9:30 A.M., INBOUND LANES
- A. BEFORE
- B. DURING - PRECONSTRUCTION
- C. DURING - CONSTRUCTION
- D. DURING - ENFORCEMENT



LOS ANGELES

6:30-9:30 A.M.
4-7 P.M.
BOTH DIRECTIONS
- A. BEFORE
- B. DURING - 1ST 7 WEEKS
- C. DURING - LAST 7 WEEKS



MIAMI

7-9 A.M. INBOUND LANES
- A. BEFORE
- B. DURING - 3 PERSON PHASE
- C. DURING - 2 PERSON PHASE

FIGURE 4.3. FREEWAY CARPOOLS (RESERVED AND REGULAR LANES)

In Miami, there were 390 3-person carpools during the period before the lanes were opened, 680 3-person carpools during the 3-person phase, an increase of 74 percent, and 540 3-person carpools during the 2-person phase, an increase of 51 percent. An average of 122 carpools used the Golden Glades parking lot for formation.

Average auto occupancy increased at the three sites: in Boston from 1.31 to 1.38, in Los Angeles from 1.22 to 1.31, and in Miami from 1.23 to 1.28 (see Figure 4.4).

In Boston, the reserved lane carried 37 percent of total persons in May and 46 percent in June during the peak period. In Los Angeles, the reserved lanes carried approximately 25 percent of total persons. In Miami a sample showed an average of 1718 persons per hour in the exclusive lane versus 2220 per hour in a general lane during the 3-person phase.

4.2 Alternate Route Use Pattern

Data on alternate routes was not collected in Miami. In Boston and Santa Monica data was collected, but it was not clear exactly what changes in volumes occurred due to the dense arterial road network and the lack of reliable seasonal adjustment factors. In Boston it was estimated that in May between 125 and 250 vehicles passing the northern-most screenline either shifted to alternate routes or did not make the trip. In June the number was about 4000 vehicles, but this large increase was due to the construction on the Expressway. At the southern end of the Expressway this large diversion to surface routes did not occur. In Los Angeles it appeared that volumes on arterials parallel to the Freeway increased 10 to 15 percent during the first seven weeks of the project. One set of volume counts indicated a return to previous levels while another set indicated that traffic volumes remained high.

4.3 Transit Use Patterns

There were significant changes in transit ridership in Los Angeles and Miami (beginning with the introduction of the express service in 1974). Daily bus ridership on all Santa Monica Freeway routes increased from 1171 trips per day before the project to 3793 trips per day during the last week of operation, an increase of 224 percent.

In Miami, in may 1974, daily ridership averaged 1064 on the newly instituted express bus service. It was estimated that 460 of these trips were previous transit trips. This number grew to 1431 daily trips by February 1976. Under-utilized routes were abandoned and service on successful routes expanded. The buses operated in the center reversible lane on N.W. 7th Avenue until March 1976 when they were transferred to the I-95 exclusive lanes. Daily

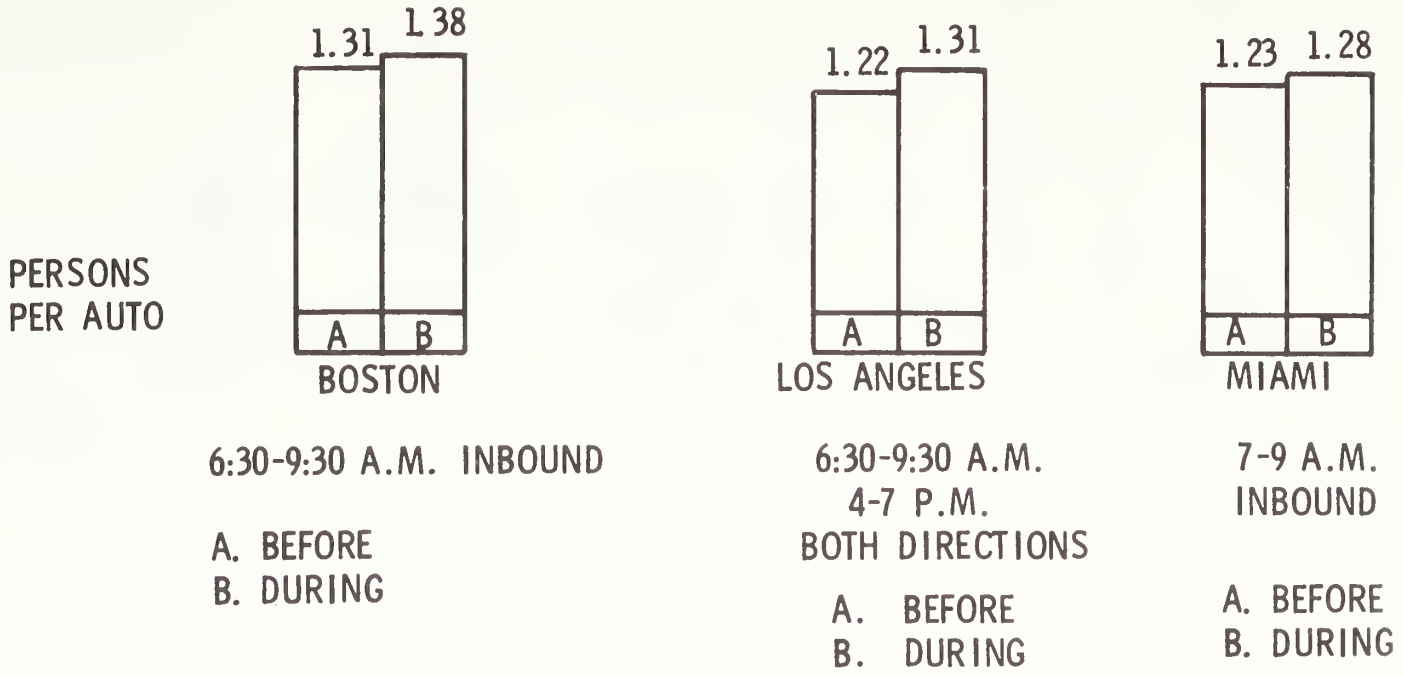
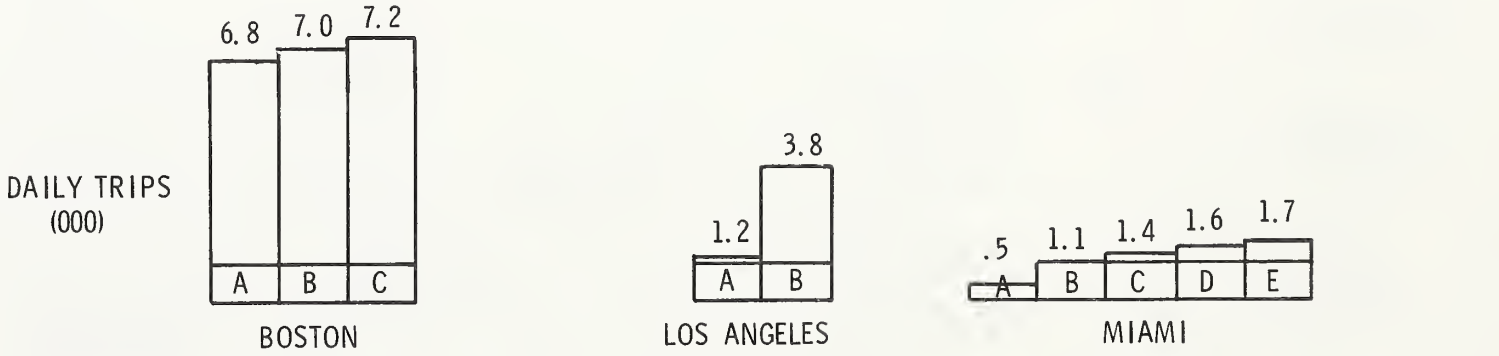


FIGURE 4.4. FREEWAY AUTO OCCUPANCY



BOSTON

A. BEFORE
B. DURING - PRE-ENFORCEMENT
C. DURING - ENFORCEMENT

LOS ANGELES

A. BEFORE
B. DURING - FINAL WEEK

MIAMI

A. BEFORE EXPRESS ROUTE EXPANSION - APRIL 1974
B. AFTER EXPRESS ROUTE EXPANSION - AUGUST 1974
C. CENTER REVERSIBLE LANE ON N.W. 7TH AVE. FEBRUARY 1976
D. DURING - 3 PERSON PHASE
E. DURING - 2 PERSON PHASE

FIGURE 4.5. DAILY EXPRESS BUS RIDERSHIP

ridership during the 3-person phase averaged 1577, an increase of 10 percent over the pre-reserved lane figure, and averaged 1683 during the 2-person phase, an increase of 18 percent.

The evidence seemed to indicate that it was the increase in coverage and schedule frequency that was responsible for the majority of the increase in bus ridership and not the time savings and reliability improvement resulting from the lanes themselves. This was best illustrated in Los Angeles where ridership increases on the four previously existing routes were only 22 percent, a small portion of the total ridership increase. After the project, ridership on all of the Freeway's express buses declined by only 17 percent. In Boston, where almost no new bus service was provided, the increase in ridership was very small, about 5 percent. Ridership on rapid rail increased by about 12 percent, possibly indicating the higher level of visibility of this mode.

It is interesting to note that in both Boston and Los Angeles the new park-and-ride routes were failures, while in Miami the Golden Glades park-and-ride lot became an integral part of the successful feeder/express bus service. The evidence indicated that park-and-ride lots can be successful, but that they must be in well chosen locations, offer the potential bus rider an increase in level of service (reduced travel times and low headways), and be marketed properly. The Miami lot is fenced, well lit, highly visible to motorists on I-95, guarded, and equipped with telephones. Buses leaving the lot travel to 4 major activity centers and passengers from the collection portion of the runs can make a free transfer if the bus they are on is not going to their desired destination. By contrast, five small park and ride facilities set up in Miami shopping center parking lots failed to attract adequate ridership. In Los Angeles, as many persons set up ad hoc park-and-ride lots in places that were more convenient to them as those who used the official park-and-ride facilities. Changes in express bus ridership at the three sites are summarized in Figure 4.5.

5. COSTS

This section discusses the costs involved in implementing and operating the three reserved lane projects. Due to the differing nature of the projects, the costs varied significantly (see Table 5.1.). For example, in Miami almost $19 million was spent just for construction of the two reserved lanes, a parking lot, and a flyover. The entire Santa Monica project cost just over $3 million, with $1.2 million being spent for data collection and evaluation and $886 thousand for bus operations. Boston spent only $245,000 for their entire project.

TABLE 5.1. PROJECT COSTS

	BOSTON		LOS ANGELES		MIAMI	
	UNIT COST	PROJECT COST ($000)	UNIT COST	PROJECT COST ($000)	UNIT COST	PROJECT COST ($000)
INVESTMENT COSTS						
LANE CONSTRUCTION		-		-		11,656
PARKING LOT(S)		-		199		1,711
FLYOVER TO LOT		-		-		2,981
PLANNING, DESIGN, AND SUPERVISION OF CONSTRUCTION		-		-		2,372
SIGNING		8		163		1,627
BUSES		-		-	20 @ 51,500	1,030
MARKETING		40		358		84
EVALUATION		55		1,232		973
PLASTIC INSERTS	3500 @ $11.	39		-		-
DRILLING HOLES	1500 @ $ 4.	6		-		-
OPERATING COSTS						
BUS OPERATIONS		-	2,588[1]	886[2]	461[1]	211[3]
ROADWAY & SIGNING MAINTENANCE		-		-		88
PARK AND RIDE LOT MAINTENANCE AND SECURITY		-		-		18
INSTALLATION AND REMOVAL OF INSERTS	26 WKS @ $3750	97		-		-
LOCAL AGENCY ADMINISTRATION		-		193		-
COURT COSTS		-		77		-
TOTAL PROJECT COSTS		245		3,108		22,751

[1] OPERATING COST PER YEAR ($000)

[2] OPERATING DEFICIT FOR 22 WEEKS

[3] OPERATING DEFICIT FOR 1 YEAR

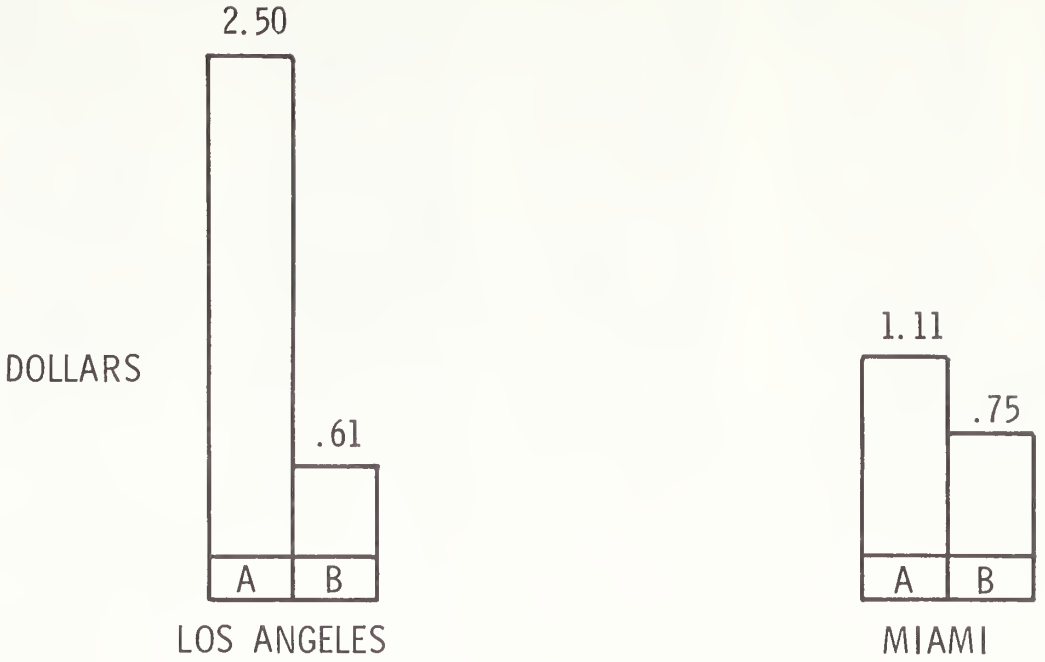


FIGURE 5.1. COST PER BUS PASSENGER

A major cost in both Los Angeles and Miami was for the increased express bus service (see Figure 5.1.). In Los Angeles, operating cost per trip had declined to $2.50 by the end of the project, while, in Miami, operating cost per trip had fallen to $1.11 in late 1977. These costs were considerably higher than the fares (61¢ in Los Angeles and 60¢ in Miami) and than the system-wide costs per trip (61¢ in Los Angeles and 75¢ in Miami). The high costs were readily explained by the nature of the service being provided: long runs, decreased headways without a proportional increase in demand, no intermediate stops, limited backhaul potential, and the near impossibility of scheduling more than one peak-period revenue run per bus. Costs were brought down by eliminating the most poorly patronized runs. In Boston, express bus service on the Southeast Expressway was provided by private carriers and, except for a new park and ride route, was not altered. The average fare was $1.25.

The major operating cost in Boston, and one that was not present at the other sites, was the daily installation and removal of the plastic inserts. The 3500 inserts (including spares) cost $38,000, and the 1500 holes cost $5,500 to drill. Each week $3,750 was spent in crew costs installing and removing them. Due to problems created by darkness and snow, Boston had planned to discontinue the use of the inserts during the winter months.

There were no costs directly attributable to increased patrolling or enforcement at any of the sites since, at most, police officers were shifted from other duty stations to the freeways. Los Angeles spent $358,000 on marketing and public information, Boston spent $40,000 , and Miami spent $127,000 for the combined I-95/N.W. 7th Avenue project ($84,000 from March 1976, which was when the express buses began operating on I-95, to May 1977).

6. SAFETY AND ENFORCEMENT

One of the major problem areas of the normal-flow reserved lane concept relates to the high violation rate (see Figure 6.1.), the difficulty of enforcement, and the potential accident hazards the lanes create. The three sites adopted different ways of dealing with these problems, with varying results.

6.1 Enforcement

Normal-flow reserved lanes have proven to be difficult to enforce and susceptible to accidents. Los Angeles, the only site with a wide median strip where police could station themselves and apprehend violators, chose a high level of enforcement, doubling the number of officers on the Freeway to 20 during the first 11 weeks of operation. It was discovered that police cars parked on the median strip

would cause traffic slowdowns. Therefore the California Highway Patrol used only motorcycles whose presence was less disruptive of the traffic flow. The violation rate was kept at between 10 and 20 percent with most of the violations occurring at the fringes of the operating periods. It was interesting to note that the on-ramp violation rate, which had been 7 percent before the project and was 5.6 percent during the project, rose to 14.3 percent after the project was terminated (preferential ramp metering was maintained after the diamond lanes had been cancelled).

In Miami, where 7 officers had been assigned to the project area, there was no median strip and the highway patrol found it almost impossible to apprehend violators safely. As a result, there was little enforcement of the lane restrictions and the violation rate soared to 75 percent. When the carpool restriction was cut to 2 occupants, the redefined violation rate declined to 37 percent.

Boston, also without a median strip, chose to create a "self-enforcing" voluntary lane during the first 5 months of operation; plastic inserts, spaced 20 to 40 feet apart, were used to separate the express lane and the normal lanes. Even so, the violation rate was as high as 80 percent, and there was a considerable amount of illegal weaving into and out of the lane.

Boston took a series of steps to decrease the number of violations. At the end of May the State began recording the license plate numbers of violators of the lane restriction and sending them letters asking them to conform to the regulations. In June the police began ticketing persons for illegal weaving, but due to the absence of a shoulder or median this effort was minimal. In October the police began enforcing the lane restrictions through a Massachusetts Department of Public Works regulation that states that if a police officer cannot reasonably stop a violator on the side of the road, then a summons can be sent through the mail. This had been the practice on the Massachusetts Turnpike for dealing with toll violators. As a result the violation rate fell to 35 percent.

The number of police on the Southeast Expressway before the opening of the reserved lane was negligible. The policy of the police was to stay off busy facilities and use a helicopter to locate incidents. At the inception of the reserved lane, eight cars patrolled the roadway. This number was soon cut in half.

6.2 Safety

The number of accidents on the Santa Monica Freeway during the project was significantly greater than before the project. There was an average of 25 accidents per week,

FIGURE 6.1. VIOLATION RATE

more than twice the rate prior to the lane implementation. The relative severity of accidents did not change due to the lanes. Rear-end accidents increased from 68 percent to 80 percent of all accidents. The number of accidents in the lane next to the reserved lane rose from 2 accidents per week to 14.8 accidents per week. The most probable cause for this increase in accidents was the large speed differential between the diamond lanes and the normal-flow lanes and people making unsafe lane changes, weaving by violators to avoid detection, and the use of the diamond lane as a safety valve. Also, the novelty of the diamond lane probably contributed to the increase in accidents at the start of the project.

Total accidents on Miami's I-95 showed no statistical increase during the operating hours of the project. However, there were a number of reserved lane related accidents attributable to two design elements of the Freeway: the elimination of the grassed median shoulders that had formerly separated the two flows and had been available for use by distressed motorists, and the solid 8-inch line that demarcated the lane. Distressed motorists unable to reach the right shoulder would stop in the reserved lane, particularly during offpeak hours, thinking it was a break-down lane.

In order to ameliorate the situation, the solid demarcation line was changed to a striped line and warning signs reading "no stopping this lane" were positioned on the facility. The Florida Highway Patrol reported that these modifications reduced the number of incidents related to motorists' confusion regarding the function of the reserved lanes during off peak hours. The other major cause of accidents was the lane changing activities required for access to the exclusive lane.

In Boston there was no significant increase in accidents on the Southeast Expressway during the non-enforcement phase. This may have been due to the presence of the plastic inserts that clearly denoted the express lane, the lack of a large differential in travel speeds, and the limited legal access to and from the lane.

During the brief enforcement period injury accidents were less than the average for the previous 7 years. By contrast, there were 8 property damage accidents compared to the historical average of 3.0. This increase was explained, in part, by the increased police surveillance of the Expressway. However, four of the nine accidents were caused by an automobile crossing illegally from the slow moving left-most normal lane into the free-flowing reserved lane.

A problem developed after 9:30 a.m. before all the inserts had been removed. Signs prohibited weaving between the hours of 6:30 a.m. and 9:30 a.m. only, and dangerous

weaving, with drivers attempting to avoid the remaining inserts, occurred after the official hours of express lane operation.

7. INSTITUTIONS AND ATTITUDES

The creation of a reserved lane from an already existing freeway lane provides both a carrot and a stick to the commuter. In Los Angeles and Boston the carrot of a congestion free ride for those willing or able to ride buses or to carpool proved too small a benefit compared to the increase in disutility experienced by the non-reserved lane users to be acceptable to the public as a whole.

In Los Angeles and Boston the stance that the media assumed proved to be a major factor in the acceptance or rejection of the reserved lanes by the public. The Santa Monica Freeway diamond lanes were an immediate media event, generating frequent newspaper articles and editorials, radio and television coverage, public debate and lawsuits. At least 245 articles and editorials appeared in the three major Los Angeles daily newspapers between January and October 1976. Newspaper coverage was highly negative, using phrases such as "chaos on Freeway," "diamonds don't glitter," and "sin and the diamond lanes." Four constantly recurring themes were operational failures of the project, aspects of coercing disincentives, bureaucratic recalcitrance, and the credibility of published data. The tenor of radio and television coverage was similar. State and local officials had proposed legislation to end the project. However, the diamond lanes were suspended by a federal judge who ruled that an environmental impact report should have been filed on the project.

In Boston no public outcry occurred during the summer months when the lane was not being enforced and when the need for the lane was closely tied to the Expressway reconstruction. However, the enforcement that began in October (after the construction had been completed) proved to be an unpopular change in project operations. Newspaper articles began to appear calling the reserved lane a "flop" and a "war against commuters". Two bills were introduced in the State Legislature, one to prohibit preferential treatment on the Expressway and the other to change the restriction to vehicles with two or more occupants. With no visible support from public officials and a vocal group of disgruntled commuters, the Commissioner of the Massachusetts Department of Public Works cancelled the project two and one half weeks after enforcement had begun.

In Miami everyone tended to gain from the project, and newspaper articles were typically descriptive and informative. The only cause for controversy was the increase in accidents.

Surveys were conducted in Los Angeles and Miami. While Angelenos were well aware of the problems of pollution, congestion and future gas shortages in their region, they never accepted the idea of the diamond lanes as a sensible solution. A corridor survey revealed that drivers felt that express bus service was the best idea for solving these problems. Ramp metering and on-ramp bypass lanes ranked second and third. The Santa Monica Freeway diamond lanes ranked a low fourth, with 19 percent of the respondents calling them "of no benefit" and 67 percent calling them "harmful."

Members of carpools formed during the Santa Monica project were sampled. Thirty percent gave the reserved lanes as the main reason for carpooling while 35 percent reported cost incentives. Express bus riders were not asked a comparable question.

In Miami, 50 percent of corridor automobile users favored the retention of the reserved lanes while only 35 percent wanted them extended to other freeways in the area. Ninetyed-four percent of bus passengers and 86 percent of carpoolers survey favored the continuation of the reserved lane on I-95, while 50 percent of transit riders and 55 percent of carpoolers favored extension of the concept to other congested freeways. Bus passengers ranked the express bus service as being more important than both the exclusive lane and the park-and-ride facility. Carpoolers found the exclusive lane, park-and-ride lot, and flyover of equal importance. When asked their primary reason for forming a carpool, 49 percent of the carpoolers on I-95 listed cost while only 23 percent stated exclusive lane time savings and 17 percent indicated energy conservation.

8. SUMMARY AND RECOMMENDATIONS

8.1 Summary of Concurrent-Flow Project Results

The three reserved lane projects have met with differing degrees of success and failure. The reserved lane on the Southeast Expressway survived for 6 months only to be cancelled suddenly two and a-half weeks after the lane restrictions became mandatory. A Federal judge shut down the Santa Monica project after 21 weeks of operation because an environmental impact report had not been filed. In Miami, the inability to enforce the lane restrictions led to a lowering of the lane qualification to two or more persons per car.

The three projects resulted in an increase in the occupancy rate of those vehicles using the facility. However, in both Boston and Los Angeles person throughput on the freeways decreased. A promising trend had developed in Los Angeles, and when the project was terminated the Freeway was carrying only 1.8 percent fewer persons in 9.4 percent

fewer vehicles, and the number of carpools had increased by 65 percent.

In Boston, after the reserved lane was instituted but before construction began, the total number of persons carried by the Expressway during the peak period was 22,400, 5 percent less than during the March pre-project period. In June, person throughput declined to 22,300, a decrease of 6 percent from March. This additonal one percent decrease was probably the result of the combination of the construction further north on the Expressway and seasonal factors. During the enforcement period, the total number of persons carried was 21,600, a decrease of 8 percent from March. Since the dominance of Boston's core area as an attraction zone indicated a much greater potential for carpooling and bus ridership than in Los Angeles, it was possible that an increase in person throughput similar to that experienced in Los Angeles would have developed had the enforcement period continued. In fact, it is reasonable to assume that all three projects suffered from the public's perception that the lanes were not permanent. It was less likely for a person to form a carpool or learn about a convenient bus route if he believed that the reserved lane project was to be terminated when construction was completed or if political pressure became too great to maintain it.

At all three sites carpooling increased by about 70 percent. In both Los Angeles and Miami the primary reason given for carpooling was cost and not the time savings from using the lanes. While it was true that the majority of the carpoolers surveyed at each site had formed carpools before the reserved lanes were instituted, and therefore, their primary incentive would have been expected to be time rather than monetary savings, in Los Angeles 35 percent of members of carpools that were formed during the reserved lanes gave cost as the main reason for carpooling while only 30 percent gave time savings. However, the number of carpools fell to within 5 percent of pre-project levels after the project was terminated. It could be that time savings from using the reserved lanes were balanced by the additonal time it took for the collection and distribution portions of the trips.

Not everyone who was eligible for the reserved lanes used them. In Miami less than one-third of the eligible carpools used the reserved lanes. In Santa Monica 22 percent of eligible carpools were in regular lanes. For persons not making long trips it was probably not worth the effort to access the reserved lanes.

At all three sites the greatest benefits accrued to users of the lanes, carpoolers and bus riders, who experienced decreases in travel times and increases in arrival time reliability. In Los Angeles and Boston, these benefits needed to be weighed against any decreases in level of service experienced by non-users of the reserved lanes.

In Los Angeles travel times increased for non-diamond lane users. In Boston, users of the regular lanes experienced a decrease in travel times during the pre-enforcement period. This was due to people shifting out of their cars and into carpools and buses on the Expressway and to other modes and routes which resulted in a 5 to 6 percent decrease in vehicles on the southern portion of the Expressway. It was also due to the "metering" of the Expressway just before the start of the express lane. As with ramp metering on the Santa Monica Freeway, this screenline metering worked well in creating free-flow conditions on the roadway. In Miami all users of the facility benefited, but this was a result of the opening of the two additional lanes, at a cost of $19 million, and had little to do with the lane restrictions.

A disappointment with the reserved lane projects was their inability in and of themselves to attract large numbers of new bus riders. In Los Angeles and Miami a large portion of the ridership increases appeared to have been the result of the increase in coverage and schedule frequency and not the travel time savings and increased reliability resulting from the reserved lanes. For most runs, the time spent in the reserved lanes did not represent a major portion of total in-vehicle travel time. However, the reserved lanes were useful in providing a focal point for the transit marketing campaigns and in creating a perceived, as well as a real, time advantage in the minds of the bus passengers. In Boston, where there were almost no transit level of service changes except decreased bus line-haul travel times, express bus ridership increased by only 5 percent. It was interesting to note that ridership on rapid rail increased by about 12 percent, possibly due to the higher visibility and public awareness of this mode.

While the feeder/express routes in Miami and Los Angeles proved to be very popular, they also proved to be very costly since few buses could make more than one run during each peak period. Park-and-ride lots at the three sites met with mixed success and this was a function of where they were situated and the frequency of the bus service. In Miami, the success of the park-and-ride service was due, in part, to the placement of a large parking lot 11 miles from the CBD at the confluence of several major highways. Buses travelled to four central city destinations and headways were low.

Another disappointment with the reserved lane concept was the number of lane violations that occurred and the difficulty of enforcing the lane restrictions. In Boston the plastic inserts did not prevent drivers from weaving in and out of the lanes. A median strip, where police could station themselves and stop violators, helped keep the violation rate in Los Angeles between 10 and 20 percent. Stiffer fines might have proven to be a deterrent, but the probability of being caught was not that great, especially

if upon seeing an officer, the illegal driver was able to weave into the adjoining lane. In Boston and Miami a median area was not available. When Boston began enforcing the lane restrictions by sending tickets through the mail, the violation rate fell from 80 to 35 percent.

One of the most serious problems with the reserved lane projects was the potential for accidents. Accidents were caused by the large speed differential between the reserved lanes and the normal-flow lanes and people making unsafe lane changes, weaving by violators to avoid detection, and by distressed motorists mistaking the reserved lane for a breakdown lane during non-operating hours. Lane changes could be limited by closely spaced plastic inserts, and reserved lane access and egress could be restricted to coincide with major entrances and exits. Boston did this to the extreme by permitting only one entrance and one exit, but motorists still managed to violate the no-weaving restrictions.

Carpool matching programs did not meet with great success. In Miami, no carpool matching program was attempted since such a program had been tried on another project and failed. In Los Angeles, commuter computer estimated that it was responsible for the formation of only 193 carpools. In Boston about 400 persons filled out carpool matching questionnaires. It was not known how many of these persons actually formed carpools. Most carpools in Los Angeles were formed among co-workers.

8.2 Recommendations for Future High Occupancy Vehicle (HOV) Priority Projects

HOV priority treatments on freeways can be divided into those involving the reservation of a lane such as concurrent-flow, contra-flow, and reversible lanes, and those using another traffic management technique, such as ramp metering and pricing. The results of the three non-separated concurrent-flow projects described in this paper point out the many generic weaknesses in this concept: the large number of violators and the difficulty of enforcement; the potential for accidents; the inability of the reserved lanes by themselves to attract large numbers of new bus riders and carpoolers; and the political problems associated with removing an already existing lane from general use.

Based on the Boston and Santa Monica results, it is not recommended that an existing lane be re-dedicated for preferential use unless there is a pressing need such as a reduction in capacity due to freeway reconstruction. If there is to be a decrease in freeway supply available to non-high occupancy vehicles, this decrease should be phased in order to cushion its effects and to encourage single occupant auto drivers to switch early to other modes or routes. A corridor whose transportation facilities are not

already saturated will cushion the transition from pre-project to post-project equilibrium by allowing former users of the freeway the option to switch to alternate routes or other modes of transit if these are preferable to carpooling, taking an express bus, or staying on the freeway's normal lanes. These concepts were well illustrated in Boston.

A comparison of the performance of these non-separated reserved lane projects with the Shirley Highway reversible lanes and the El Monte busway indicates that when concurrent-flow lanes are separated from the general lanes by a concrete barrier or an empty safety lane, the accident and enforcement problems are virtually eliminated and the reserved lanes are better able to perform their function of attracting and carrying high occupancy vehicles. The appearance of permanence seems to contribute a great deal to convincing people to switch to HOV's.

Quite often these permanently or semi-permanently separated configurations are not feasible for economic and/or engineering reasons. Boston attempted the minimum in physical lane separation by installing plastic inserts every 20 or 40 feet between the reserved and regular lanes. Unfortunately, these inserts did not prevent a large amount of illegal weaving between the two lanes. Not only did non-carpoolers switch into the reserved lane, but carpoolers illegally left the lane to exit the Expressway.

The evidence indicates that there should be a median strip between the two directions of flow to provide both an area for motorcyle police to station themselves to control the violation rate and a safe area for distressed motorists to stop (see Figure 8.1.). To reduce the dangers of lane changing between two lanes travelling at significantly different speeds, the reserved lane entry and exit points should be limited to the beginning and end of the reserved segment and to a few intermediate points. The potentially large speed differential between the reserved lane and the regular lanes could possibly be reduced by electronic signs on the freeway that would limit the speed in the reserved lanes to some amount greater than in the regular lanes. This speed limit could be enforced if bus drivers were instructed to adhere to it. This concept has never been tested.

If the reserved lane configuration calls for inserts and a median, then it must be determined whether or not to leave the inserts in place on a 24 hour basis. It is costly to install and remove the inserts, the operation tends to confuse motorists, and it cannot be performed in the snow or dark. If the inserts were permanent, the lane restrictons would not necessarily have to be in effect or enforced on a 24-hour basis. However, this arrangement could be confusing to motorists as was the case in Miami where the solid

striping used to separate the lanes during the early months of the project resulted in the reserved lanes being mistaken for breakdown lanes during the non-restricted hours. Other drawbacks are that the inserts could create a safety hazard at night or during slippery conditions and plowing would be extremely difficult.

If space permits, the median could be shifted to the area between the reserved lane and the normal lanes as is the case with the El Monte Busway (see Figure 8.2.). Permanent plastic inserts would separate this safety lane from the rest of the roadway. The inserts would be spaced far enough apart so that this empty lane could be accessed by slow moving police and distressed motorists. Carefully designed slip-ramps would provide entry to and exit from the lanes at a few intermediate points. These ramps would be denoted by inserts, striping, and special pavement treatment so as not to be confusing to motorists.

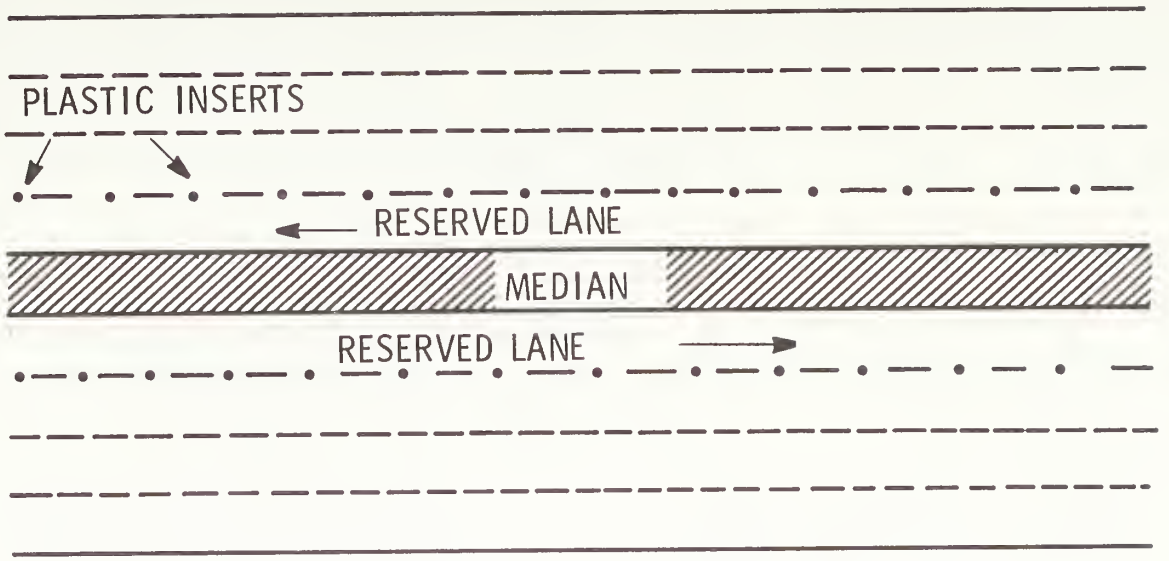
Concurrent-flow lanes are applicable when the flow is balanced in each direction. When there is a large imbalance in peak directional flows, and if sufficient capacity exists in the off-peak direction, then contra-flow or reversible lanes would be more appropriate.

In addition to the careful selection of the most appropriate form the HOV lanes will assume, this analysis has revealed factors related to site characteristics, implementation procedures, transit operations, and media treatment that must be considered.

The primary characteristic of the site that defines the market potential for the reserved lanes is a CBD that is the focal point for regional employment. This ensures a ready market for express bus patrons and facilitates the formation of carpools. In order to avoid citizen protest, it is important that the reserved lanes appear to be well utilized to those travelling in the regular lanes and appear to be permanent.

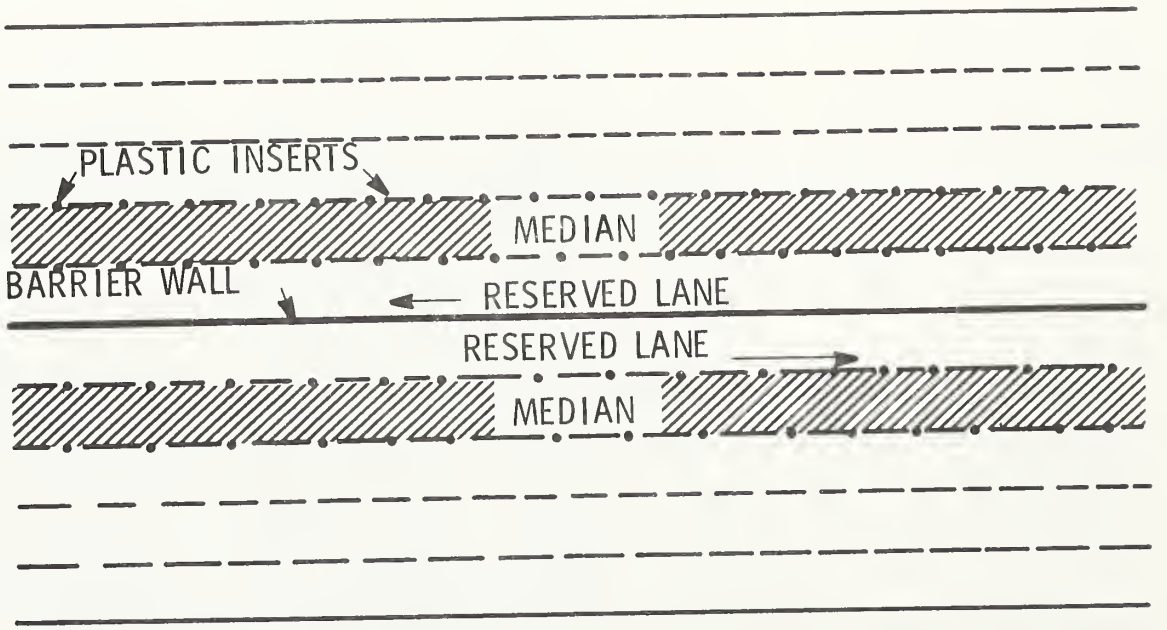
Any increase in express bus operations should focus on the development of new feeder/express routes with the feeder component used to expand transit coverage, preferably serving more densly populated neighborhoods that currently have poor access to transit. Free and efficient transfer capabilities should be provided at park-and-ride lots if the buses go to different destinations. However, demand for priority facility bus services has proven to be inelastic with respect to fare; therefore, the fare should reflect the quality of the service being provided.

Park-and-ride service should be provided only from lots that are distant from the CBD and have good transit and highway access. The lots should be adjacent to the freeway and be large enough to support low headway service to



- INSERTS SEPARATE RESERVED LANE FROM REGULAR LANES
- MEDIAN FOR POLICE AND DISTRESSED MOTORISTS
- ENTRY AND EXIT LIMITED TO BEGINNING AND END AND A FEW INTERMEDIATE POINTS

FIGURE 8.1. CONCURRENT-FLOW RESERVED LANE WITH INSERTS AND MEDIAN



- SAFETY LANE BETWEEN RESERVED AND REGULAR LANES
- SAFETY LANE USED BY POLICE AND DISTRESSED MOTORISTS
- INSERTS SEPARATE SAFETY LANES
- ENTRY AND EXIT LIMITED TO BEGINNING AND END AND A FEW INTERMEDIATE POINTS VIA CAREFULLY DESIGNED SLIP-RAMPS
- BARRIER WALL BETWEEN TWO DIRECTIONS OF FLOW

FIGURE 8.2. CONCURRENT-FLOW RESERVED LANE WITH SAFETY LANE AND INSERTS

several major destinations. Lots should be guarded, well lit, highly visible to the motorist, and contain amenities such as sheltered waiting areas, telephones, and toilets. The lots should have a convenient and adequate waiting area for afternoon kiss-and-ride automobiles. The transit operator should be aware of the high cost of operating this express bus service. High occupancy vehicles, such as double deck and articulated buses, could be used on these routes to minimize driver costs.

The public should be made aware of all aspects of the reserved lane project as early as possible. Commuter Computer estimated that carpool formation took an average of one month following a request. All travel options should be clearly described including estimates of level-of-service for each one.

Ramp metering, freeway metering, and pricing can be used along with, or in lieu of, reserved lanes. Ramp metering is relatively inexpensive, easy to install, and acceptable to the public. It worked well on the Santa Monica Freeway, making the average trip time both shorter and less variable. Many of the ramps provided preferential treatment, and the violation rates were low. A form of freeway metering was attempted in Boston and resulted in a decrease in travel time. However, freeway metering does not afford high occupancy vehicles preferential treatment.

The majority of carpoolers in Miami (surveyed at the park-and-ride lot) and Los Angeles indicated that their primary reason for carpooling was to save money. Thirty-five percent of members of carpools formed during the Santa Monica project reported cost incentives as the primary reason for carpooling while 30 percent listed the diamond lane. These results indicate that parking or toll policies favorable to carpools, in addition to preferential lanes, would do much to increase carpooling. The revenues generated could be used to expand the express bus service which would further increase the use of high occupancy vehicles.

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